Remarks

The Examiner has pointed out how the difficulties of bonding materials of different thermal expansion coefficients have been overcome by inserting an intermediate layer showing a gradual change in composition, where this change was achieved through the use of powder metallurgy (PM) with gradual changes in the relative proportions of the powders building up the intermediate layer as taught by Zimmer (U.S. 3,284,174) or concurrent deposition of multiple elements in changing ratios as taught by Slattery (U.S. 5,988,488). While the sintering of the PM layer will involve diffusion, this diffusion is principally restricted to distances comparable to the size of individual grains and therefore very short compared to the thickness of the intermediate layer. The diffusion that occurs in Zimmer's process will reduce the original gradients introduced into the powder precursor ("green") and is therefore undesirable and not at all responsible for forming such gradients. Forming the layer using PM technology, has some distinct disadvantages:

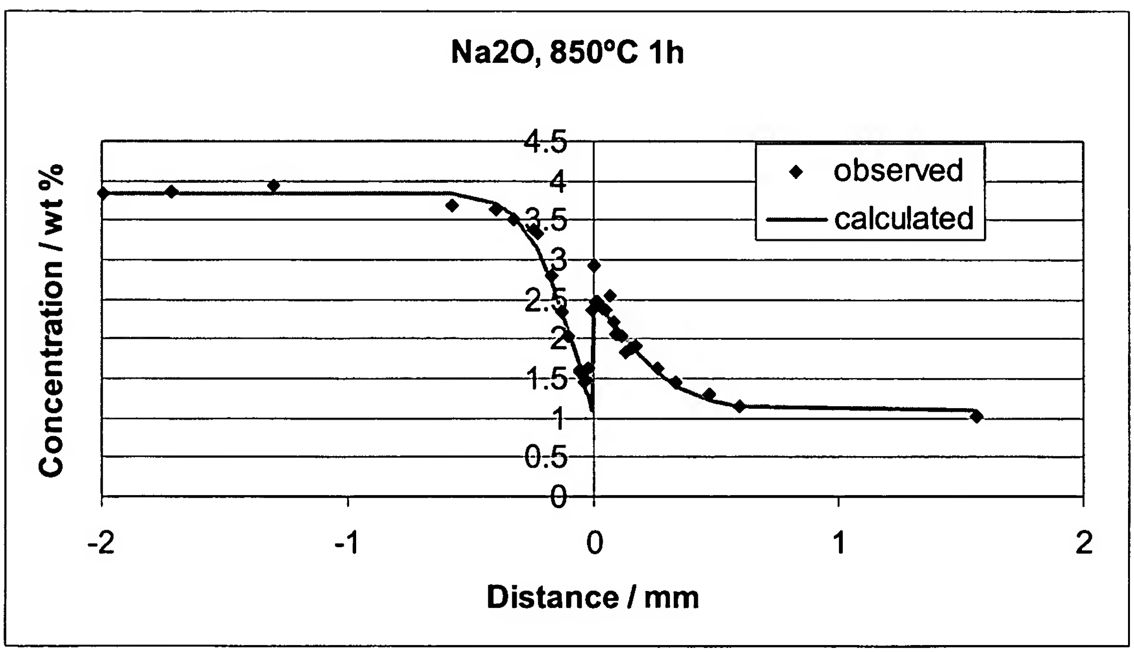
- The method is well established for metals, but does not have its direct counterpart in glasses. However, glasses are a preferred option for bonding of many MEMS / semiconductor parts.
- PM parts often have porosities exceeding those of the solid components to be bonded together, resulting in physical properties of the intermediate layer that differ from those of components.
- A PM layer showing compositional gradients will contain two or more distinct phases in varying proportions; and even after sintering these phases will be recognizable leading to micro scale in-homogeneities.

Building up a layer with powder metallurgy showing compositional gradients, followed by subsequent sintering and short-distance diffusion is both physically and process-wise very different from creating the entire compositional profile through the usage of diffusion processes between originally distinct layers. Some of the advantages achieved by applying large scale diffusions include:

- The method is readily applicable to glasses of various compositions.
- The glass constitutes a single phase, which even on the micro-scale displays smooth compositional gradients.
- Large thickness (compared to what is economical to achieve with Physical or Chemical Vapor Deposition) can readily be obtained.
- The process is simple to control and reproduce accurately.
- The intermediate layer has no porosity.

The unique challenges faced by the diffusion method are:

- The different components will diffuse at different rates, so after diffusion for a period of time under a given temperature, some of the elements will hardly display any gradient, while others still are showing a steep gradient close to the original interface.
- Because of matrix effects (structural differences between the two original layers) some glass systems will show uphill diffusion, leading to undesirable compositional discontinuities near the interface. An example of such a discontinuity is shown in the following figure.



The methods through which these challenges can be overcome are:

- Computational simulation of the diffusion processes to identify sets of (1) starting compositions (2) time-temperature path in the furnace that lead to optimal profiles in thermal expansion coefficients.
- Addition of elements to the precursor materials that modify the glass structure to enhance (or retard) the diffusion processes.
- Use of thicker layers of material than what ultimately is needed to provide a source of elements available for the diffusion processes, followed by lapping of the excess material prior to inserting the intermediate layer between the materials being bonded.

The approaches taken to overcome these difficulties further emphasize the fundamental differences between the powder metallurgy and the large scale diffusion approaches to solve the issue of bonding parts with significant different thermal expansion coefficients.

Conclusions

The method presented in this application offers several novel advantages of special importance to applications in various emerging technology areas such as MEMS packaging. The applicant has narrowed the claims to make the invention patentable over prior art, and has shown how the nature of the invention as defined in the revised claims differs fundamentally from the patent of Zimmerman (US 3,284,174).